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Systematic Review
Orthognathic Surgery

Cone beam computed tomography volumetric airway changes after orthognathic surgery: a systematic review

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Abstract. The aim of this systematic review was to provide a structured overview of three-dimensional airway volume changes in relation to various orthognathic surgeries. Clinical human studies performing pre- and postoperative three-dimensional airway volume assessments to investigate volumetric changes of the airway after orthognathic surgery were included. Predetermined inclusion and exclusion criteria were applied in an extensive search of the PubMed, Embase, and Web of Science electronic databases. The cut-off date was set to January 1, 2022. Forty-one articles reporting retrospective and prospective case–control and case series studies were included. All studies were determined to be of medium quality (moderate risk of bias). The included studies were categorized by type of intervention. Pre- and postoperative volumes were extracted from the available data, and volume changes as a percentage of the preoperative levels were calculated. Isolated mandibular setback surgery generally decreased the airway volume. Isolated maxillary or mandibular advancement, bimaxillary advancement, and surgically assisted maxillary expansion generally increased the airway volume in the total airway and oropharynx, among which the effect of bimaxillary advancement surgery appeared most significant. High heterogeneity exists in the terminology and definitions of the airway and its segments. A more uniform methodology for airway volume measurement is needed to provide an insight into the impact on the airway of specific types of surgical intervention. In conclusion, airway volumes are affected after orthognathic surgery, which may be of clinical significance, especially in patients who are predisposed to obstructive sleep apnoea.

Keywords: Orthognathic surgery; Mandibular advancement; Le Fort osteotomy; Oropharynx; Nasopharynx; Mandibular osteotomy; Three-dimensional imaging; Systematic review.

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Dentofacial deformities may lead to compromised function, poor aesthetics, and possible narrowing of the upper airway.[1,2] Previous studies have demonstrated that skeletal deformity with maxillary deficiency results in smaller nasopharynx airway volumes, and that skeletal deformity with mandibular deficiency results in smaller hypopharynx airway volumes.[3] Orthognathic surgery, i.e. the correction of skeletal deformities by surgical displacement of the maxilla and/or the mandible, alters the relationship between the bony structures and the soft tissues, including those that are closely related to the anatomy of the upper airway. Hence, orthognathic surgery may lead to changes in the airway volume.[4]

The effect of orthognathic surgery on the airway has been described in various studies. A decrease in the airway volume in the oropharyngeal airway has been reported after mandibular setback in class III patients.[5] Mandibular setback combined with maxillary advancement appears to attenuate the reduction in the oropharyngeal airway volume.[6,7] In contrast, advancement of the mandible has often been associated with an increase in the airway volume,[8] and similarly maxillomandibular advancement surgery.[9] However, as different definitions and anatomical borders have been applied for the airway and the airway segments in the current literature, direct comparisons of the results are not possible.

Several systematic reviews on the effects of orthognathic surgery on the airway have been published in recent years. Christovam et al.[10] reported airway volume measurements obtained from computed tomography (CT) and magnetic resonance imaging (MRI) studies. Their results showed a significant increase in the airway volume after maxillomandibular advancement and a significant decrease after mandibular setback, isolated or in combination with maxillary advancement. He et al.[11] investigated only patients with class III malocclusion and showed less reduction in the airway volume after bimaxillary surgery than after mandibular setback surgery only. More recently, Shokri et al.[12] focused on mandibular advancement and demonstrated a significant volumetric increase in the upper airway. However, a comprehensive overview of the current literature on the effects of different types of orthognathic surgery on volumetric changes to the total airway and to the airway segments is still lacking.

Over the last decade, cone beam computed tomography (CBCT) has become recognized as an accurate and reliable tool for the three-dimensional (3D) evaluation of the upper airway.[13,14] In addition to the advantages of lower costs and a reduced radiation dose when compared to medical CT or MRI, CBCT allows imaging of the airway in a seated position and with shorter acquisition times, thereby reducing the opportunity for patient movement, which can affect volumetric measurements of the airway.[15] For reasons of both anatomical location and clinical relevance, the upper airway is often divided into a number of segments: nasopharynx, upper and lower oropharynx, and hypopharynx.[13] However, no consensus exists regarding the nomenclature of the different airway segments, and the definitions of the borders and anatomical landmarks used to describe the airway and its segments are highly inconsistent.[16]

Therefore, the aim of this systematic review was to provide a structured overview of 3D volumetric changes of the airway after various orthognathic surgeries. Airway volumes measured on CBCT scans were assessed in order to gain an insight into the relationship between specific types of surgery and the volumetric changes of the airway. To ensure the comparability of the outcomes between studies, the airway segments used in the studies that were finally included were matched to a predefined airway segments framework.

Materials and methods

Protocol and criteria

The PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was used to guide the conduct of this systematic review (http://prisma-statement.org/PRISMAStatement/). The following outcomes were assessed: (1) volumetric airway changes in cubic millimetres (mm^3) or cubic centimetres (cm^3), and (2) the type of orthognathic intervention.

A search was conducted in the PubMed, Embase, and Web of Science electronic databases. The time frame for the search was from database inception (as CBCT has only recently been introduced) to January 1, 2022. The following primary keywords were applied in the search: CBCT, cone-beam computed tomography (MeSH), three-dimensional imaging (MeSH), 3D CBCT, CBCT, digital volume tomography (MeSH), tomography (MeSH), compact computed tomography. The following were used as secondary keywords: airway, pharynx (MeSH), nasopharynx (MeSH), and oropharynx (MeSH). The screening of titles, abstracts, and full texts was performed by two authors (FH and RS). The title and abstract of each article retrieved in the search were scanned for all of the exclusion criteria; if this was insufficient to determine inclusion, the full text was screened only against the exclusion criteria. The full text of remaining articles was screened by the same two authors against the inclusion criteria. To be included, all inclusion criteria had to be met. Any uncertainty or disagreement was resolved by discussion with a third author (YR).

Inclusion and exclusion criteria

The inclusion criteria were English or Dutch as the language, prospective or retrospective clinical studies, orthognathic surgery as the intervention, pre- and post-treatment CBCT 3D volumetric assessments available, CBCT acquisition with the patient in an upright position, airway definition clearly described or illustrated, and treatment group with 10 or more patients. Exclusion criteria were animal studies, patients with syndromes and non-healthy patients, patients with obstructive sleep apnoea syndrome (OSAS), patients with any airway disease, expiratory flow studies, aerodynamics or airway pressure studies, two-dimensional (2D) volumetric assessments, case series with fewer than 10 patients in the treatment group, age younger than 16 years, and systematic reviews.

Quality assessment

All studies were rated once by two authors for risk of bias (FH, RS), according to the National Heart, Lung, and Blood Institute quality assessment tools for case–control studies and before–after studies with no control group (https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools). This tool is designed to assess studies for risk of bias and consists of 12 yes/no questions concerning the research question, study population, sample size justification, recruitment of the cases and controls from the same population, the use of pre-specified inclusion and exclusion criteria applied

Table 1. Description and definitions of the borders and reference planes to define the airway.

Borders	Nasopharynx	Oropharynx		Hypopharynx
		Middle pharynx	Inferior pharynx	
Superior	SS plane	PNS plane	U plane	E plane
Inferior	PNS plane	U plane	E plane	EF plane
Anterior	PNS frontal plane	PNS frontal plane	PNS frontal plane	PNS frontal plane
Posterior	C2P plane	C2P plane	C2P plane	C2P plane
Lateral	MS plane	MS plane	MS plane	MS plane

Borders	Description
Most superior border	Sphenoid sinus (SS) plane: axial plane parallel to FH, passing through the most inferior part of the floor of the sphenoid sinus
Most inferior border	Epiglottis (E) plane: axial plane parallel to FH, passing through most superior part of the epiglottis
Anterior border	Posterior nasal spine (PNS) frontal plane: frontal plane perpendicular to FH, passing through PNS
Posterior border	C2P plane: frontal plane perpendicular to FH, passing through the most posterior part of the second cervical vertebra
Lateral border	MS plane: sagittal plane perpendicular to FH, passing through the lateral surfaces of the maxillary sinus (left and right)
PNS plane	Axial plane parallel to FH, passing through PNS
U plane	Axial plane parallel to FH, passing through most inferior point of the uvula
PNS plane frontal	Frontal plane perpendicular to FH, passing through PNS
EF plan	Plane parallel to the FH passing through the bottom of the epiglottis

FH, Frankfort horizontal.

uniformly, the definitions of cases and controls, random selection of study participants, the use of concurrent controls, exposure assessed prior to outcome measurement, exposure measures and assessment, blinding of exposure assessors, and statistical analysis. A 'yes' answer scores 1 point, while a 'no' answer scores 0 points.

If risk of bias is significant, the study is deemed to be of poor quality. A maximum of 12 points could be obtained, with a score of 1–4 indicating 'low' quality, a score of 5–9 'medium' quality, and a score of 10–12 'high' quality. In the case of disagreement regarding the rating, a consensus was reached through discussion with a third author (YR).

Anatomical landmarks, borders, and reference planes of the airway

Considering the inconsistency in the definitions of the upper airway and the upper airway segments, the method outlined below was proposed for the data analysis in this review, based on five easy-to-determine soft and hard tissue anatomical landmarks in the midsagittal plane and five cross-sectional planes (two frontal and three axial planes). A detailed description and definition of the borders and reference planes is provided in Table 1. Fig. 1 illustrates the five reference planes in the sagittal view in a 2D lateral cephalogram and in a 3D CBCT surface model.

In short, the upper airway is divided into four segments: nasopharynx, middle pharynx, inferior pharynx, and the hypopharynx. The middle and inferior pharynx together form the oropharynx.

An airway segments framework

Due to the high heterogeneity in the definition of the airway and its segments, the available data on the same airway segment from different studies were converted into comparable measurements following a strict protocol. First, the anatomical landmarks and reference planes used in the original studies were compared to the proposed borders (Table 1, Fig. 1). Considering the variations in landmark definition in the individual studies, the concept of a 'reference field' was proposed that accommodates more reference planes within a predefined range of variations. The reference field was primarily based on the proposed plane, with an extension to include a limited amount of deviation of the planes that were not exactly the same as the proposed one, but were anatomically close and were used in four or more of the finally included studies. Fig. 2 illustrates the ranges of the deviations in landmark positioning with the associated reference fields, which served as a predefined airway segments framework to enable volumetric data conversion from the finally included studies.

Volumetric data interpretation and inclusion

Pre- and post-treatment volumetric data were extracted from all included studies. In the case of multiple post-treatment follow-ups, the latest available data were used, thereby providing the longest follow-up results. Volumetric data were extracted according to the protocol described below.

(1) Direct data inclusion: originally reported data were included directly when the definition of the airway and its segments concurred with those proposed (Table 1, Fig. 1).
(2) Data inclusion with note: when the reference planes used in an individual study were not the same as the proposed planes, but fell within the borders of the reference fields as described previously, the volumetric data were included. Specifically, for the anterior border of the total airway and nasopharynx, anatomical reference points were accepted when they were positioned between the frontal plane perpendicular to Frankfort horizontal (FH), passing through posterior nasal spine (PNS) and a plane from PNS to sella. For the superior border of the oropharynx and inferior border of the

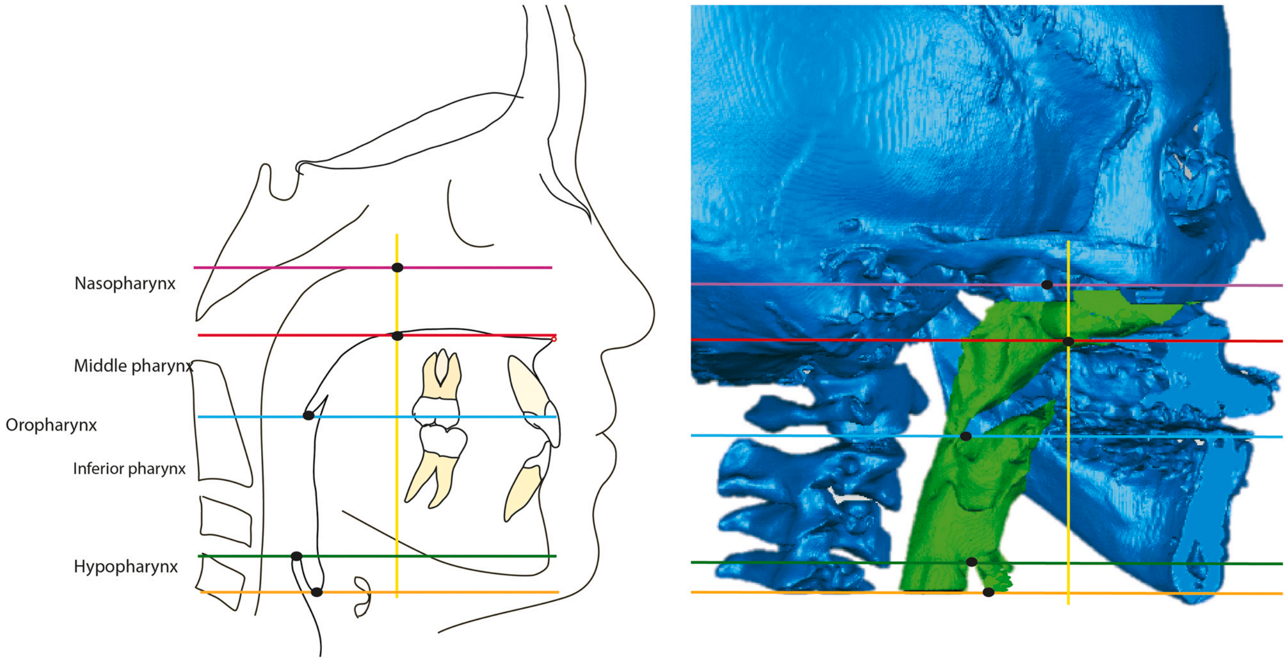

Fig. 1. The total airway and airway segments evaluated in this systematic review, for data analysis. (A) Schematic diagram of the reference points and planes for the airway segments in two-dimensional lateral cephalograms. (B) Reference points and planes for the airway segments in a CBCT surface model in sagittal view. The purple line indicates the most superior border of the airway; the red line indicates the lower border of the nasopharynx; the blue line indicates the lower border of the middle pharynx; the green line indicates the lower border of the inferior pharynx and oropharynx; and the yellow line indicates the most inferior border of the airway and the hypopharynx.

nasopharynx, reference planes through the PNS plane to the anterior superior part of C1 were accepted. For the inferior border of the oropharynx and superior border of the hypopharynx, reference planes passing through the most superior part of the epiglottis or between the anterior superior part of C3 and anterior inferior part of C3 were accepted. For the inferior border of the hypopharynx and total airway, reference planes passing through the bottom of the epiglottis to a plane passing through the superior anterior part of C4 were accepted (Fig. 2).

(3) Data exclusion: when deviations in landmark positioning or reference planes exceeded the borders of the reference fields, no data were included in the final analysis.

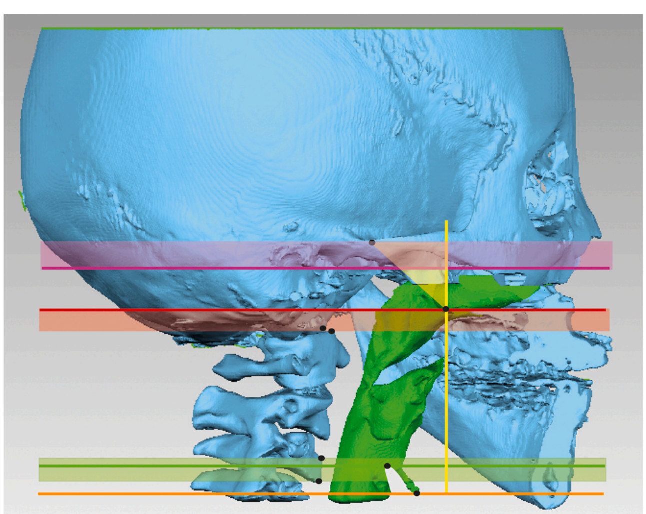

Fig. 2. Predefined airway segments framework with reference fields. The thick lines refer to the proposed reference planes of the borders of the respective airway segments; the shaded boxes refer to the reference fields within which variations in the reference planes from different studies were accepted. Red indicates the ranges for the superior borders of the oropharynx (PNS plane to anterior superior part of C1) and green indicates the ranges for the inferior borders of the oropharynx (anterior superior part of C3 to anterior inferior part of C3). The yellow triangle indicates the accepted anterior borders (PNS to sella to the frontal plane perpendicular to FH passing through PNS).

Results

Study selection

The first database search identified a total of 7543 articles. After the removal of duplicates, 2365 articles remained for screening of the titles and abstracts. Of these, 2280 articles were excluded after application of the exclusion criteria. The remaining 85 articles, along with two additional studies identified through other sources, qualified for full-text assessment against the inclusion criteria; 46 studies were further excluded. Finally, a total of 41 studies met the inclusion criteria and were included for data analysis in this systematic review.[7,17–56] The PRISMA flow diagram and an overview of the selection of articles is presented in Fig. 3.

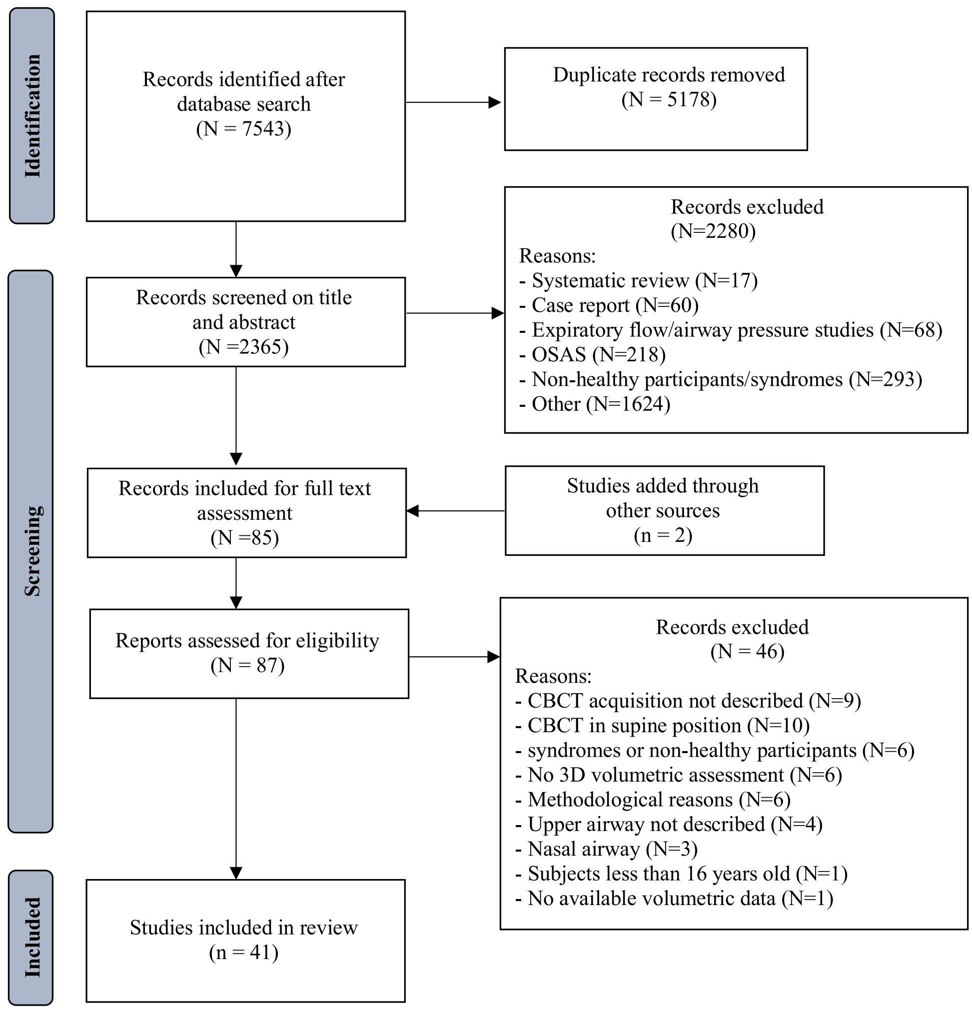

Fig. 3. Flow diagram of the selection process based on the PRIMSA guidelines. (OSAS, obstructive sleep apnoea syndrome; CBCT, cone beam computed tomography).

Quality assessment of the included studies

No clinical trials could be identified. Only two studies included a control group. Eight out of the 41 studies performed a power analysis to determine the minimum number of subjects needed. Blinding of the assessors was reported in five of the included studies. In 12 studies, the reliability of the results was not tested by repeating selected measurements, which was considered as confounding. In the quality assessment, four studies scored 5 points, nine studies scored 6 points, 16 studies scored 7 points, nine studies scored 8 points, and three studies scored 9 points. All studies were qualified as medium risk of bias. The quality of each individual study is reported in Supplementary Material Table S1.

Characteristics of the included studies

Out of the 41 studies that were finally included, 38 studies had subjects with a class III malocclusion, 17 with a class II malocclusion, and six with maxillary deficiency. These 41 studies were divided into subgroups based on the malocclusion and the surgery type. An overview is presented in Table 2. Fourteen of the 41 studies included patients undertaking different types of surgeries. Supplementary Material Table S1 reports detailed information regarding the characteristics of the 41 included studies.

General characteristics

With the exception of Valladares-Neto et al.,[51] all of the studies were single-centre case series. Most of the included studies were retrospective ($n = 29$) in study design, and only 12 were prospective. The sample size varied from four to 102 patients per group. Although most studies included both male and female patients, only one study (Panou et al.[39]) looked into sex-specific treatment responses and reported a significant decrease in oropharynx volume only in male patients ($P < 0.05$). With regard to ethical approval, 40 of the 46 studies confirmed ethical approval for taking CBCT scans. No such information was available for five studies (Irani et al.,[18] Canellas et al.,[20] Lee

Table 2. An overview of the included studies.

Surgery types in each malocclusion	Number of studies
1. Class III malocclusion	38
1.1. Single jaw: BSSO setback	9
1.2. Single jaw: Le Fort I advancement	5
1.3. Double jaw: Le Fort I advancement and BSSO setback	19
1.4. Double jaw: Le Fort I impaction and BSSO setback	5
2. Class I and class II malocclusion	17
2.1. Single jaw: BSSO advancement	6
2.2. Double jaw: maxillomandibular advancement	11
3. Transverse maxillary deficiency	6
3.1. Surgically assisted expansion	6
Studies including more than one surgery type	14
1.1. + 1.2. + 1.3.	1
1.1. + 1.3.	6
1.1. + 1.2. + 2.1.	1
1.2. + 2.1. + 2.2.	1
1.3. + 2.2.	5

BSSO, bilateral sagittal split osteotomy.

et al.,[41] Kochel et al.,[49] Raffaini and Pisani[52]). There was a large variation in the follow-up, ranging from 1.5 to 90 months.

Specific characteristics

In the 38 studies including patients with class III malocclusion, 14 investigated single-jaw surgeries (nine BSSO setback and five Le Fort I advancement) and 24 investigated double-jaw surgeries (19 Le Fort I advancement + BSSO setback and five Le Fort I impaction + BSSO setback). The only two studies with a control group were in this subgroup: Uesugi et al.[23] included 16 participants with a normal occlusion and no symptoms of sleep-disordered breathing and Hsieh et al.[42] included 36 participants with a normal occlusion and no history of orthognathic surgery.

In the studies on class I or II malocclusion, only two surgery types were included: single-jaw BSSO advancement ($n = 6$) and double-jaw maxillomandibular advancement ($n = 10$). The follow-up was typically 6 months. With the exception of Chang et al.,[21] all of these studies were retrospective.

In the four studies on maxillary transverse deficiency, only tooth-borne expansion devices were used, with different expansion protocols. The surgical procedures prior to the expansion varied and included bilateral Le Fort I osteotomy, selective bilateral zygomatic buttress osteotomies (Yazigi et al.[55]), and osteotomy with or without pterygomaxillary disjunction (Rômulo de Medeiros et al.[56]).

Airway volumetric changes after orthognathic surgery

The 3D airway volumetric changes and skeletal changes after the different types of orthognathic surgery are presented in Supplementary Material Table S2. The percentage airway volume changes at follow-up in relation to the pre-surgery volumes in the individual studies are illustrated in Fig. 4 (class III: 1.1., 1.2., 1.3., 1.4.), Fig. 5 (class I and II: 2.1., 2.2.), and Fig. 6 (transverse maxillary deficiency: 3.1.). The patterns mentioned above can be visualized in these figures, in addition to the surgical displacement of the jaw at the sagittal level and the number of included subjects.

In patients with a class III malocclusion, the airway volume showed a general pattern of reduction after single-jaw BSSO setback surgery, in all three airway segments and in the total airway (Supplementary Material Table S2, 1.1.), with the exception of Chang et al.[21] who reported a tendency towards a slight increase in the airway volumes.[21] In contrast, single-jaw Le Fort I advancement surgery showed a pattern of increase in airway volume (Supplementary Material Table S2, 1.2.). Double-jaw surgery, including a Le Fort I advancement and BSSO setback, resulted in inconsistent changes in the airway volume (Supplementary Material Table S2, 1.3.). Double-jaw surgery with Le Fort I impaction and BSSO setback, however, consistently showed decreases in the airway volume (Supplementary Material Table S2, 1.4.). In the 38 studies included in this analysis, the percentage change in airway volume from the pre-surgery airway volume was within the range of + 40% to − 30% (Fig. 4).

In patients with class I and II malocclusions, regardless of single-jaw or double-jaw surgery, the volume of the oropharynx increased in 16 studies ($P < 0.05$ in 11 studies). The volumes of the other airway segments also showed a general pattern of increase (Supplementary Material Table S2, 2.1., 2.2.). Fig. 5 shows that the airway volume increase in patients who underwent a double-jaw advancement surgery was approximately double that of the patients who underwent a single-jaw BSSO advancement.

In patients with a maxillary transverse deficiency, surgically assisted expansion of the maxilla showed a tendency towards a volume increase in the different segments of the airway (Supplementary Material Table S2, 3.1.). Significant increases ($P < 0.05$) in hypopharynx volume were observed after osteotomy of the palate and 0.5 mm expansion on alternate days (Liu et al.[54]), in oropharynx volume after a complete or selective osteotomy followed by 0.9 mm expansion a day (Yazigi et al.[55]), and in nasopharynx volume after Le Fort I osteotomy with or without pterygomaxillary disjunction followed by 0.5 mm expansion a day (Rômulo de Medeiros et al.[56]). The percentage changes varied from + 6% to + 16% and did not appear to be related to the surgery type or the expansion protocol (Fig. 6).

Discussion

The aim of this systematic review was to provide a structured overview of 3D volumetric changes of the airway after various orthognathic surgeries. The findings demonstrated a clear impact of orthognathic surgery on volumetric measurements of the airway. The impact appeared to be related to the type of orthognathic surgery, i.e. the direction of the jaw displacement. In other words, the magnitude of the jaw displacement did not show a consistent pattern of the effect. A meta-analysis, however, was not possible due to the high heterogeneity in different aspects of the study designs and outcome reporting of the included studies.

Only two systematic reviews on airway volumetric measurements obtained from

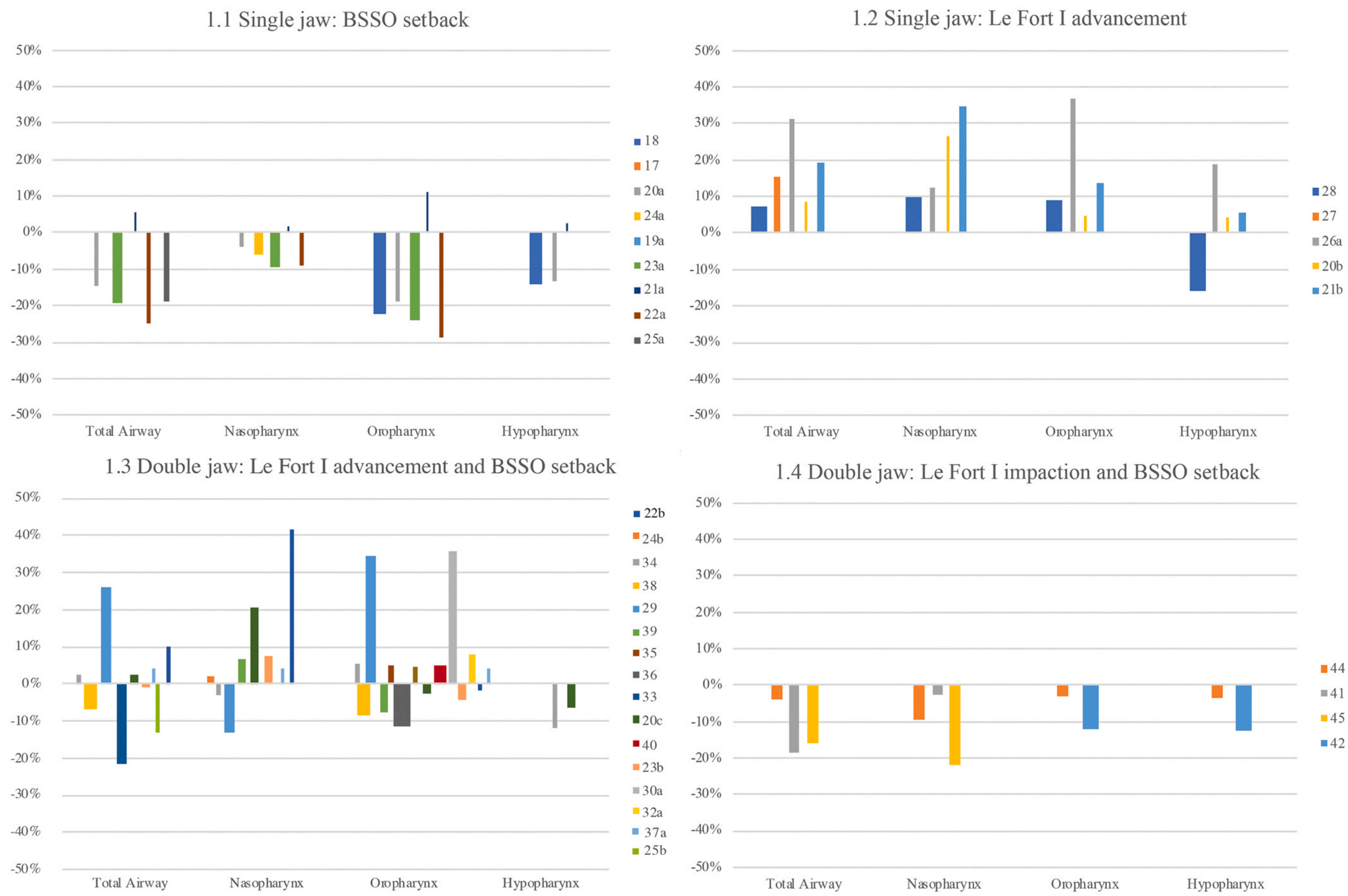

Fig. 4. Bar graphs of the percentage volume changes after orthognathic surgery in studies on class III malocclusion. The *y*-axis shows the percentage airway volume change: (post-treatment – pre-treatment)/pre-treatment × 100%. The *x*-axis shows all studies, with one bar for each study; the width of the bar represents the number of patients included in the study (wider bars indicating a larger number and narrow bars a smaller number). All bars are ordered according to the amount of skeletal change (left, largest jaw movement; right, smallest jaw movement, no jaw movement last).

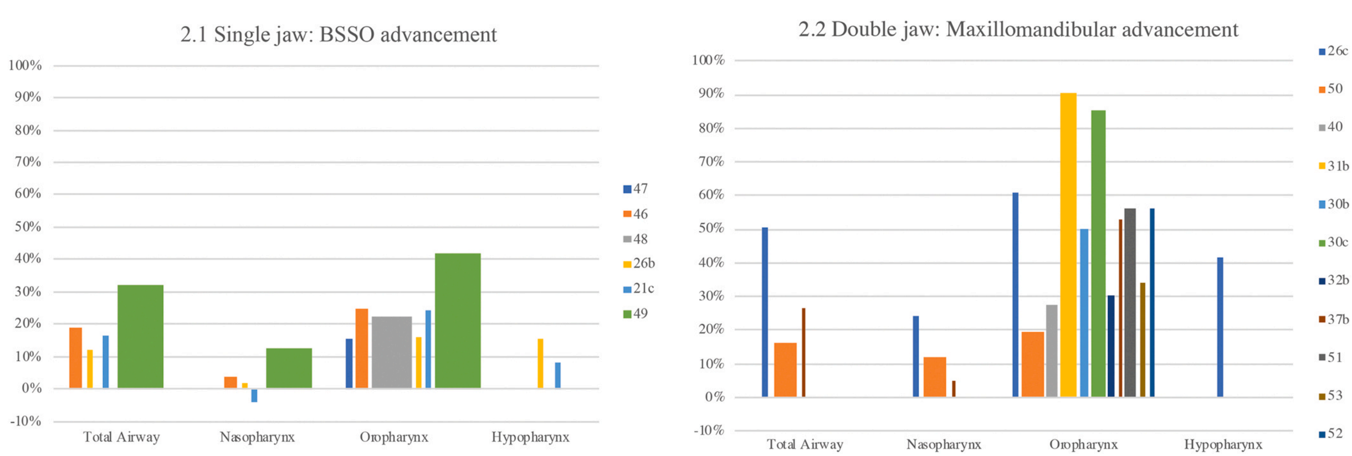

Fig. 5. Bar graphs of the percentage volume changes after orthognathic surgery in studies on class I and II malocclusion. The *y*-axis shows the percentage airway volume change: (post-treatment – pre-treatment)/pre-treatment × 100%. The *x*-axis shows all studies, with one bar for each study; the width of the bar represents the number of patients included in the study (wider bars indicating a larger number and narrow bars a smaller number). All bars are ordered according to the amount of skeletal change (left, largest jaw movement; right, smallest jaw movement, no jaw movement last).

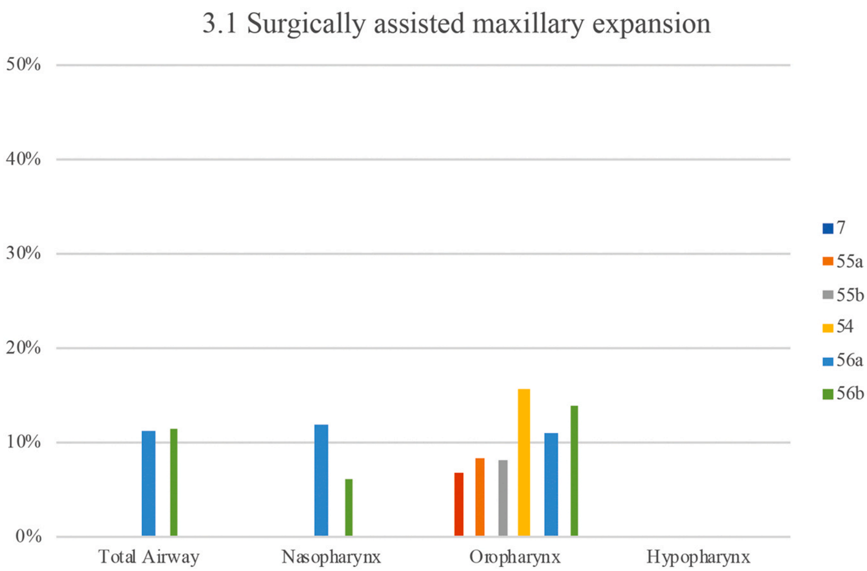

Fig. 6. Bar graph of the percentage volume changes after orthognathic surgery in studies on maxillary transverse deficiency. The *y*-axis shows the percentage airway volume change: (post-treatment – pre-treatment)/pre-treatment × 100%. The *x*-axis shows all studies, with one bar for each study; the width of the bar represents the number of patients included in the study (wider bars indicating a larger number and narrow bars a smaller number). All bars are ordered according to the amount of skeletal change (left, largest jaw movement; right, smallest jaw movement, no jaw movement last).

CBCT have been published previously, with one demonstrating less reduction of the volume after bimaxillary surgery than mandibular setback only in patients with a class III malocclusion,[11] and the other showing a significant volume increase after mandibular advancement in patients with mandibular deficiency.[12] In comparison, the present study is novel in providing a comprehensive overview of the volumetric changes of both the total airway and the three airway segments, and including the different types of orthognathic surgery reported in the literature.

It is well known that the upper airway anatomy can affect airway obstruction problems. In individuals with sleep apnoea, the size of the upper oropharyngeal airway is smaller compared to control subjects without sleeping disorders.[57] The surrounding craniofacial structures or body fat can decrease the upper airway volume, leading to an increased likelihood of pharyngeal collapse.[58] As also shown in this review, isolated mandibular setback surgery resulted in a reduction in the volume of the total airway and the three airway segments in almost all of the included studies, which is the opposite of isolated maxillary advancement surgery, which resulted in an increase in the airway volume. Bimaxillary surgery including mandibular setback resulted in an increase in the airway volume in most of the studies. In those that showed a reduction in the airway volume, the magnitude of the reduction was less than isolated mandibular setback surgery. This implies that when a mandibular setback is indicated, bimaxillary surgery could be favoured over single mandibular setback surgery[6,11] in order to minimize the negative effect on the airway volume, and thereby reduce the risk of postoperative pharyngeal collapse.[59–61]

Of the 41 included studies only three, all on patients with a class III malocclusion, looked into the effect on sleep after orthognathic surgery. Canellas et al.[20] performed a clinical assessment and used a questionnaire to screen for OSAS after mandibular setback only or Le Fort I maxilla advancement and mandibular setback. A significant reduction in the oropharyngeal airway volume was observed in patients undergoing mandibular setback alone. In other words, patients undergoing a double-jaw surgery did not show a reduction in the airway volume. Nevertheless, there were no signs or symptoms of OSAS in any of the patients. Uesugi et al.[23] measured the apnoea–hypopnoea index (AHI) with a polysomnography system in patients after mandibular setback and Le Fort I advancement in addition to mandibular setback. The AHI did not change in either group. Lee et al.[33] reported a significant decrease in oropharynx volume in 22 patients undergoing bimaxillary surgery including Le Fort I advancement and BSSO setback. The outcomes of endoscopic examination and a sleep study showed that, although none of the patients had sleep-related symptoms before surgery, three (13%) were newly diagnosed with mild or moderate obstructive sleep apnoea and six (27%) showed increased loudness of snoring 3 months after surgery.[33]

As expected, isolated mandibular advancement and bimaxillary advancement generally increased the volume of the oropharynx and of the total airway. Collectively, the postoperative airway volume, relative to the preoperative level as a percentage, increased more in patients with bimaxillary advancement than in those with mandibular advancement only; furthermore, the largest increases reported in the former category (85–90%) were twice those in the latter (32–42%). These results indicate a clear advantage of bimaxillary surgery in patients who are predisposed to sleep-related problems. Bimaxillary advancement has indeed been reported as an effective surgical treatment for sleep apnoea.[62–64] The mechanism is assumed to be that the anterior–posterior dimension of the pharyngeal airway is increased by forward traction of the maxilla, the mandible, and associated soft tissue structures, which may lead to a consequent reduction in pharyngeal collapse and improvement in the AHI.[65–67]

Although only four studies were eligible for final inclusion in the category of surgically assisted maxillary expansion, the results from these studies showed an evident tendency towards an increase in the volume of the total airway, nasopharynx, and oropharynx, regardless of the surgery procedure or the expansion protocol. This is in agreement with the outcomes of previous reports, where surgical maxillary expansion procedures demonstrated a positive effect on the function of the nasopharynx and improved sleep apnoea.[68–70]

Although CBCT shows significant advantages over conventional cephalograms to visualize different craniofacial structures and investigate volumetric airway changes, it is not without limitations. For example, non-standardized CBCT acquisition protocols including patient positioning and patient movement or swallowing during the scan, can all affect the airway volumetric measurement.[15] In the present review, only studies with a standardized patient positioning protocol were included to reduce the risk of alterations between different scans. In addition, only studies with CBCT acquisition in an upright position were included, since differences are seen in the upper airway morphology between the supine and upright positions.[71] Gravity can produce movements of the oropharyngeal soft tissue structures in response to postural changes between sitting upright and lying in the supine position.[72] Another limitation is the reliability of the airway assessment on CBCT scans. Nevertheless, the current literature shows that the intra- and inter-examiner reliability of volumetric airway measurements varies between moderate and excellent.[73] In the present study, 12 of the 41 included studies were determined to have a risk of bias in the reliability of the airway measurements.

The quality of all of the included studies was determined to be moderate (medium risk of bias). This outcome is mainly related to the fact that no randomized clinical trials could be identified, that only two studies included a control group, and that a study power analysis and blinding was applied only in a few studies. Though one can argue that there are practical barriers, often related to ethical considerations or availability problems, to including these parameters, they remain important aspects in quality assessment.

Due to the high heterogeneity in the definition of the airway and the airway segments across the different studies, the available data on the same airway segment from different studies had to be converted for the measurements to be comparable. Another aspect of heterogeneity is the follow-up. When multiple postoperative CBCT scans were available, only the latest available data were used. Although the longest follow-up measurements may have excluded the effect of immediate postoperative relapse of the jaw position more than the shorter-term follow-up measurements, the interpretation and comparison of measurements from a large range of follow-up periods needs to be made with caution.

In conclusion, within the limitations of this review, it may be concluded that (1) high heterogeneity exists in the terminology and definitions of the airway and the airway segments. A more uniform methodology of airway volume measurement is needed to provide more insight into the impact of a specific type of surgical intervention. (2) Isolated mandibular setback surgery generally decreases the airway volume in the total airway and all three airway segments; isolated maxillary or mandibular advancement, bimaxillary advancement, and surgically assisted maxillary expansion generally increase the airway volume in the total airway and oropharynx, among which the effect of bimaxillary advancement surgery appears most significant. (3) Evidence is lacking on the relationship between airway volume changes and the development of signs or symptoms of obstructive sleep apnoea. (4) Future studies are recommended to consider multicentre trials with a large sample size and standardized CBCT acquisition, airway volumetric measurement protocol, and follow-up period, and preferably also a clinical assessment for signs or symptoms of obstructive sleep apnoea preoperative and postoperative.

Ethics approval and consent to participate

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Competing interests

None.

Patient consent

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ijom.2022.05.013.

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